FY02 Highlights

- Overview
- Architecture Concepts
- *Exploration Hurdles*
  - Space Transportation
  - Power
  - *Crew Health and Safety*
  - Human and Robotic Operations
  - Space Systems
- Technology Planning
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- Future Direction

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Hurdles: Crew Health and Safety

Crew health & safety risks from hazards such as radiation, hypogravity, and weightlessness increase greatly as space missions extend beyond Earth's orbit and increase in duration from months to years.

***FY02 Accomplishments Addressing Crew Health & Safety Hurdle*:**

- Published preliminary guidance for integrating human requirements in NEXT mission and architecture designs (NASA TM-2002-210785)
- Commissioned the National Research Council *Safe On Mars* report for analysis of surface radiation, organic carbon detection, surface hazards, soil and dust properties, possible heavy metals, and atmospheric dynamics (electrostatic discharge and wind)
- Defined requirements for an artificial gravity transportation vehicle
- Improved radiation analyses and evaluated concepts to mitigate risks to crew health
  - Advanced radiation protection mission analysis tools with improved data bases, transport algorithms, and flight data validation
  - Evaluated crew mission doses for Mars surface, Gateway, and Callisto missions
  - Evaluated radiation protection afforded by induced magnetic fields intrinsic to the Mini-Magnetospheric Plasma Propulsion system

Hurdles: Crew Health & Safety –
Human Mission Design Guidelines/Capabilities

The human element is likely the most complex and difficult one of mission design; it significantly influences every aspect of mission planning, from the basic parameters like duration to the more complex tradeoffs between mass, volume, power, risk, and cost. For engineers who rely on precise specifications in data books and technical references, dealing with the uncertainty and the variability of designing for human beings can be frustrating. When designing for the human element, questions arise more often than do definitive answers.

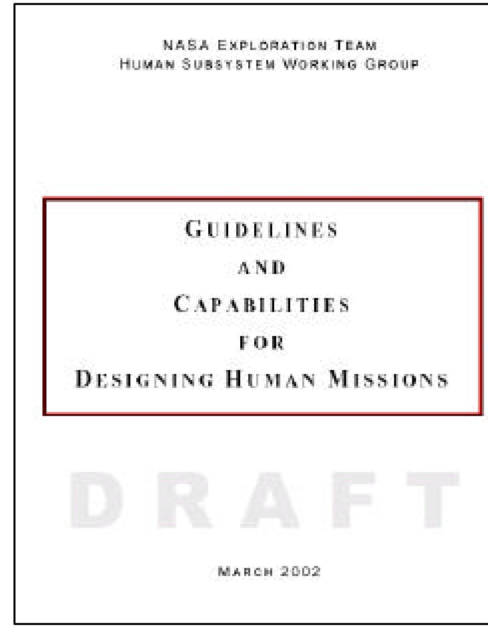
Beyond this statement of cause-and-effect, human-driven requirements are highly variable because of destination, operational environment, mission objectives, and more. Often, the precise quantification of parameters for a human mission is difficult without further study or precise definition of a specific mission architecture. Each mission design requires several iterations as the effects of the crew on the system architecture (and vice-versa) coalesce. For this reason, *Guidelines and Capabilities for Designing Human Missions* – published by NEXT – is a tool for understanding the many tradeoffs inherent in planning a human space flight mission.

In this document, key drivers on human safety, health, and performance are conveyed as simply as possible. The fundamental concepts and definitions required for decision-making and the design tradeoffs of current alternatives are described. By integrating this information into mission trade studies, mission planners can better address the most important human needs. Only material necessary to mission designers in the conceptual design phase is included. The finer details of the vehicle design including human and crew accommodations are not within the scope of this document.

NASA/TM–2002–210785
http://advtech.jsc.nasa.gov/reference_rack.shtm
http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-01/index.html

Human Mission Design Guidelines/Capabilities

- NEXT published *Guidelines and Capabilities for Designing Human Missions* which:
  - Identifies the points of intersection between humans and mission considerations such as architecture, vehicle design, technologies, operations, and science requirements
  - Provides clear, top-level guidelines for human-related exploration studies and technology research that address common questions and requirements. As a result, ongoing mission trade studies will consider common, standard, and practical criteria for human interfaces


NASA Exploration Team
Human Subsystem Working Group

GUIDELINES
AND
CAPABILITIES
FOR
DESIGNING HUMAN MISSIONS

DRAFT

March 2002

- Purpose:
  - To synthesize the current thinking of experts who have spent considerable time considering future missions in and beyond low-Earth orbit
  - To provide a simple overview of key human requirements and considerations that drive the success of a crewed mission
  - To introduce some of the problems that must be solved or resolved in planning for human mission planning
  - To supply mission planners with the requisite tools for making decisions appropriate to a given mission, without exhaustively cataloging all possible designs for all possible missions

Hurdles: Crew Health & Safety – National Research Council *Safe On Mars* Report

Safe on Mars, Precursor Measurements Necessary to Support Human Operations on the Martian Surface – a National Research Council study commissioned by NEXT – examines the role of robotic exploration missions in assessing the risks to the first human missions to Mars. Only those hazards arising from exposure to environmental, chemical, and biological agents on the planet were assessed. Of critical importance is whether it will be necessary to return Martian soil and/or airborne dust samples to Earth prior to the first human mission to Mars to assure astronaut health and safety.

To ensure that this report included all previously identified hazards, the National Research Council referred to the most recent report from NASA's Mars Exploration Program/Payload Analysis Group (MEPAG). The National Research Council concluded that the requirements identified in this report are indeed the only identifiable elements essential for NASA to pursue in order to mitigate potential hazards to the first human missions to Mars.

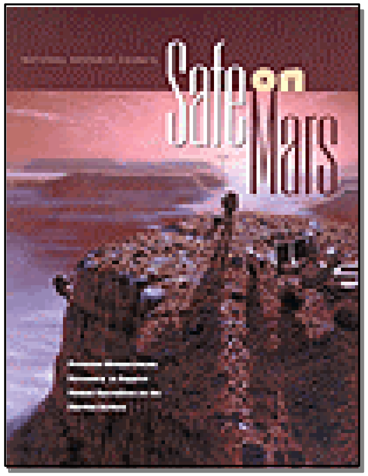
The primary assumption is that a long-stay mission to Mars will take place, as such a mission would levy the more stringent demand for the safety of astronauts while in the Martian environment. This does not imply that the National Research Council endorses the long-stay mission as a baseline NASA mission, nor that the National Research Council concluded that the long-stay mission is, in total, the least hazardous option.

http://www.nap.edu/books/0309084261/html/

Hurdles: Crew Health & Safety

National Research Council *Safe On Mars* Report

- This study, commissioned by NEXT, defines and prioritizes the many precursor measurements required for an initial human visit to Mars
- Principal recommendations:
  - – Highest priority is to measure radiation (charged particles and neutrons) on the Martian surface
  - – Organic carbon detection will determine if a sample return is needed prior to the first human mission
    - If the measurements recommended by the report can be performed in-situ on Mars surface, and if no organic carbon is detected above the life detection threshold (to be set by NASA, but 0.1 ppb example quoted), no sample return is required prior to the first human visit
  - – Map the landing operations area for humans in sufficient detail to identify hazards
  - – Measure certain mechanical and chemical properties of Martian soil and dust
  - – Measure the concentrations of certain hazardous heavy metals
  - – Mitigate the known atmospheric hazards (electrostatic discharge and wind)



Hurdles: Crew Health & Safety – Artificial Gravity Requirements Definition

Artificial gravity created by a rotating vehicle is a potential countermeasure to the deleterious effects of long-duration microgravity on humans. NEXT has developed an artificial gravity vehicle concept for a human mission to Mars based on the following design parameters:

- 1-g continuous centripetal acceleration (artificial gravity)
- 4 revolutions per minute (rpm) rotation rate
- Approximately 56-meter rotation radius.

These design parameters are taken from ground-based human studies which have established "comfort boundaries" for humans in an artificial gravity environment. In this context, comfort does not imply luxury; the implication is the mitigation of symptoms of motion sickness.

Minimum Gravity: This limit aims to provide adequate floor traction for mobility. The minimum required to preserve crew health is currently unknown. Various studies provide values for minimum gravity between 0.035-g and 0.3-g.

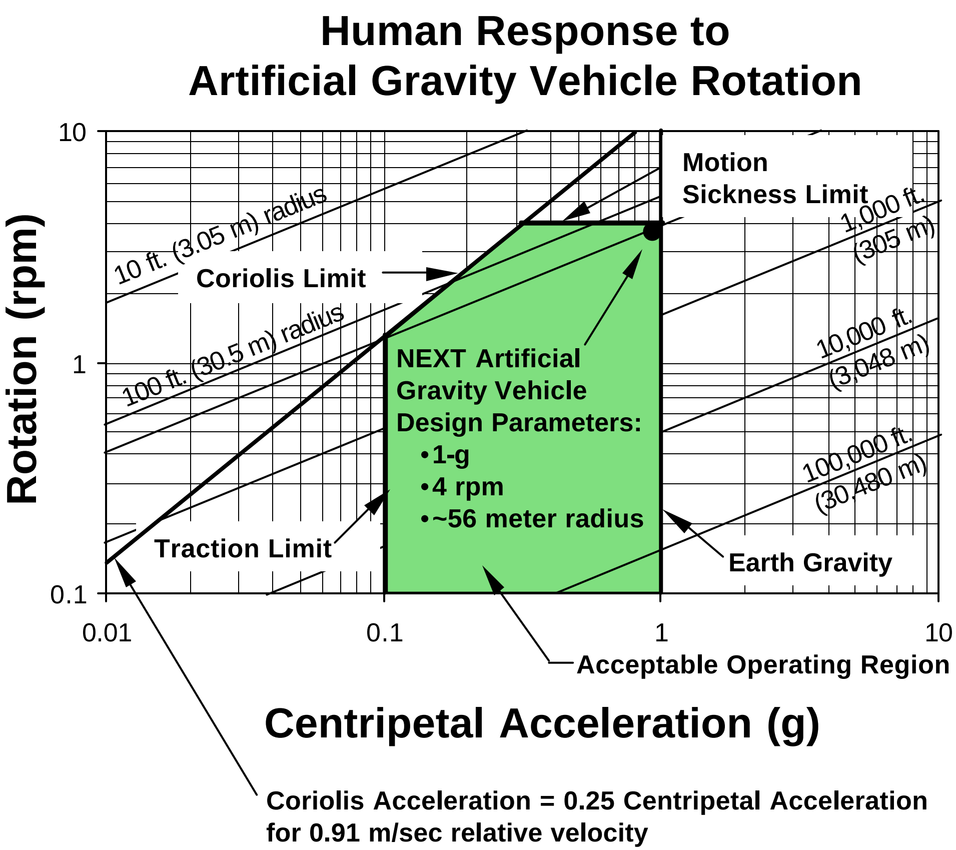
Maximum Gravity: This applies primarily to the centripetal acceleration of the rotating vehicle. Studies provide values between 0.9-g and 1.0-g. There is no rationale for increasing this limit beyond this level.

Maximum Rotation Rate: This limit aims to avoid motion sickness caused by the cross-coupling of normal head rotations with the habitat rotation. In Earth-based centrifuge experiments, when subjects turn their heads about any axis not aligned with the centrifuge rotation, they experience illusions of rotation about a mutually perpendicular axis. This mismatch between visual and vestibular senses of motion is a major contributor to motion sickness. Various studies provide values for maximum rotation rate between 2 and 6 rpm.

Maximum Tangential Velocity: This value should be large compared with the relative velocity of crew within the habitat. The goal is to minimize the ratio of Coriolis acceleration to centripetal acceleration. An accepted value is to limit Coriolis acceleration to 1/4 centripetal acceleration for a prograde walking velocity of 0.91 meters per second.

Artificial Gravity Requirements Definition

- **Rationale For Artificial Gravity**
  - Artificial gravity is a countermeasure for the deleterious effects on humans of long-duration microgravity exposure
    - Loss of bone mineral density
    - Skeletal muscle atrophy
    - Orthostatic hypertension
  - Potentially required for “long Mars and beyond” missions
- **Comfort in Artificial Gravity**
  - ***Maximum Rotation Rate***
    - This limit aims to avoid motion sickness caused by the cross-coupling of normal head rotations with habitat rotation
    - 4 rpm limit is consistent with a number of published studies
  - ***Minimum Gravity***
    - This limit of 0.1-g provides adequate floor traction for mobility
  - ***Maximum Gravity***
    - For reasons of both comfort and cost, this generally should not exceed 1-g
  - ***Minimum Tangential Velocity (Coriolis limit)***
    - Goal is to minimize the ratio of Coriolis acceleration to centripetal acceleration
    - A person’s apparent gravity should not change by more than 25% when walking at 0.91 meters per second



Hurdles: Crew Health & Safety – Improved Radiation Shielding Design Tools

Shielding is the first line of defense for astronaut protection against space radiations which initiate biophysical events leading to health risks. Advanced design tools have been developed for shielding optimization analysis to evaluate different shielding strategies and their impact on mission architecture. The development of such frameworks leading to software for “anytime/anywhere” radiation calculations coupled with multifunctional use of onboard materials with design optimization methods is the key to understanding the advantage of various shielding strategies. Methods, validation of methods, and method integration of shielding tools into design frameworks have been developed to optimize designs to reduce crew health risks. Physics-based high performance computational procedures allow the implementation of modern engineering methods for shield design which reduce computational time by orders of magnitude. The figure depicts the results from the Immersive/Collaborative Engineering Environments Design Tool which analyzes three-dimensional radiation field variables in near real-time.

Significant improvements have been included in the physics-based codes used to perform shield analyses to better understand crew health risks. A meson production database, a meson transport algorithm, a particle straggling propagator and straggling database have now been incorporated into the High Charge and Energy Transport Code (HZETRN). The addition of the straggling propagator provided the key to understanding spacesuit garment transmission characteristics observed in laboratory testing. These results can be used to design improved spacesuits to reduce radiation risks to crew members during extravehicular activities such as the assembly of large telescopes in Earth’s Neighborhood. Model validation with available space-based assets is a high priority. The developed dynamic low-Earth orbit environmental models have shown agreement with 15 years of Space Shuttle thermoluminescent dosimeter data to 10 percent level. The tested low-Earth orbit neutron environment has also shown agreement with measurements. An improved Tissue Equivalent Proportional Counter model and International Space Station Shield model have been developed to further improve flight validation of these radiation shielding design tools and methodologies.

http://sirest.larc.nasa.gov/

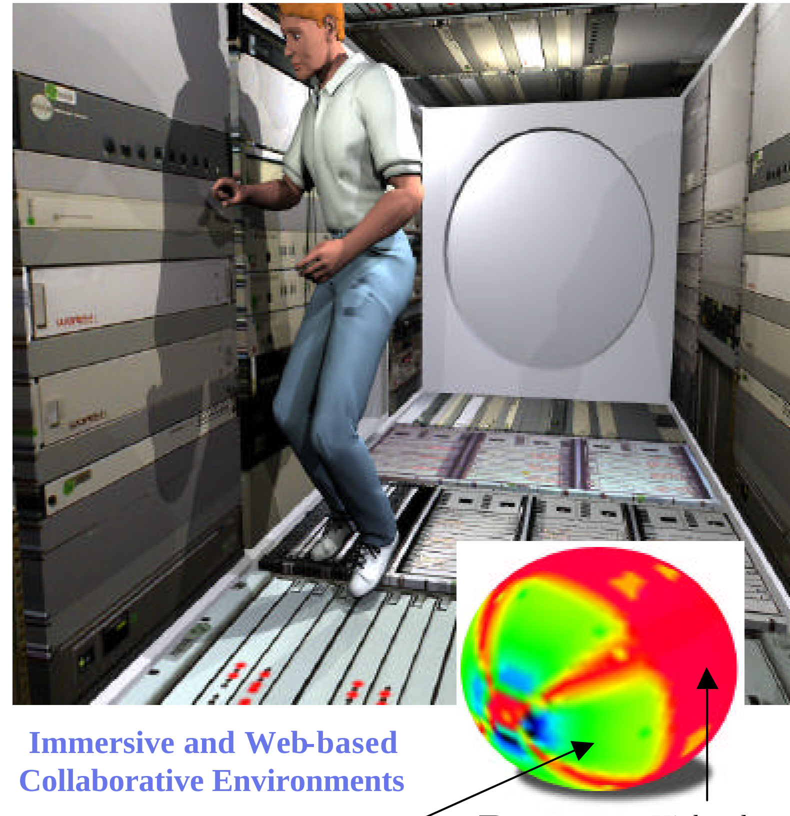
Improved Radiation Shielding Design Tools

Design Tool Enhancements

- Expanded engineering design environment to include enhanced multi-disciplinary optimization software, Web-based interfaces and immersive environment applications to improve the overall design process and time required
- Created multiple databases and improved transport algorithms
  - Nuclear database verified by international colleagues

Validation

- Demonstrated agreement of predicted Low-Earth-Orbit neutron environment with flight measurements
- Developed International Space Station shield model for further Low-Earth-Orbit environment validation with flight measurements
- Improved Tissue Equivalent Proportional Counter model to enhance International Space Station flight validation activity
- Working with Odyssey Science Team to validate Mars radiation environmental models



Immersive and Web-based Collaborative Environments

Dose Distribution

Collaboration

- Conducted First Space Radiation Shielding Technology Workshop (90 participants; 6 countries)
- Developed World Space Congress NEXT live action exhibit on "Innovative Engineering Methods for Shield Design" including Gateway, International Space Station, and Hybrid Brayton Nuclear Electric Propulsion TransHab concept

Hurdles: Crew Health & Safety – Radiation Exposure Analysis for Mission Studies

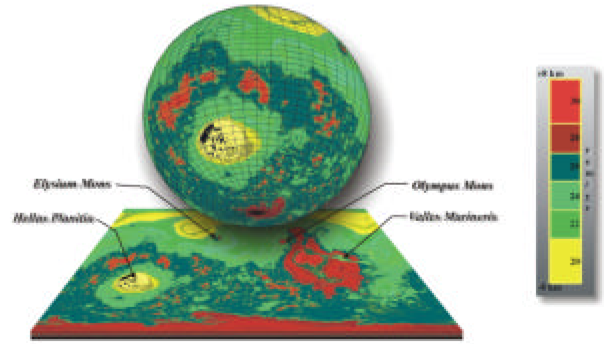
Additional modeling and validation efforts are underway to enhance our capabilities to perform radiation exposure analyses for mission studies. The basic computational procedures are coupled to variable geometry models of vehicles and habitats for time serial optimization of the mission designs to perform shield technology trade studies. The tools have been enhanced to enable mission studies for the Lunar Gateway, a Mars mission, and a Jupiter (Callisto) mission. The Mars surface environmental model has been added to the Space Ionizing Radiation Environments and Shielding Tools (SIREST) website. It has been demonstrated that the Mars surface neutron environment depends on local surface materials leading to a seasonal dependent environmental model. This may also provide an alternate method for locating surface water. Efforts are currently underway to validate the results using Mars Odyssey mission data. The "anytime/anywhere" software framework now supports near-Jupiter exploration mission scenarios with added environmental models. This software is used to help NEXT develop design reference missions. The ultimate goal is to optimize mission parameters and vehicle designs to minimize the risks to astronauts from the damaging effects of space radiation.

Hurdles: Crew Health & Safety

Radiation Exposure Analysis for Mission Studies

Mars Surface Mission Studies

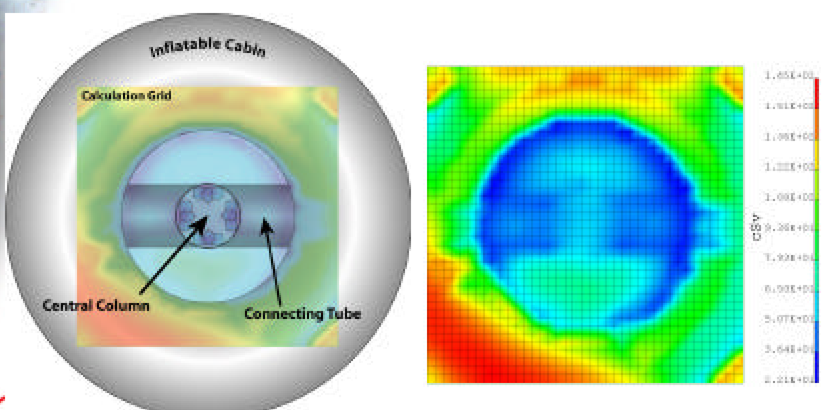
- Confirmed that Mars surface neutron environment depends on local surface materials
- Added Mars surface environmental model to Space Ionizing Radiation Environments and Shielding Tools
- Results in better predictive tools/models to understand and mitigate risks to crew members



Predicted Mars surface skin dose equivalent

Gateway Mission Study

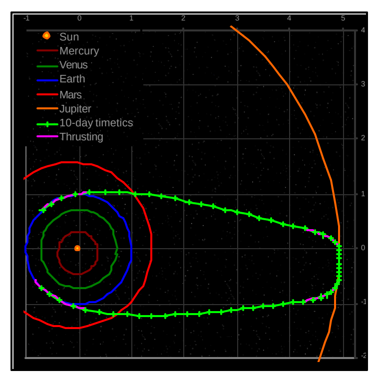
- Determined required shielding for the Gateway concept to mitigate risks to crew members from Solar Particle Events



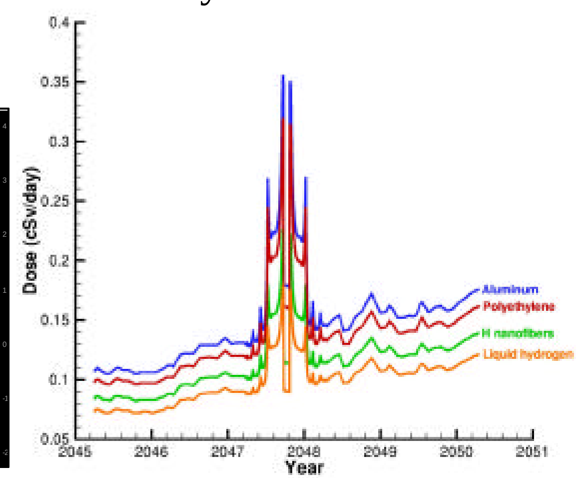
Gateway Solar Particle Event Analysis

Callisto Mission Study

- Evaluated shielding provided by fuel tanks for Callisto mission studies for various propulsion options and trajectories to optimize vehicle configurations for crew safety and shield mass reduction.



Callisto mission trajectories



Callisto mission daily exposure

Al2219, $CH2_X$, H-GNF, LH_2

Hurdles: Crew Health & Safety –
Mini-Magnetospheric Plasma Propulsion (M2P2) for Exploration Missions

The M2P2 system operates in the solar wind plasma. Solar wind plasma pushes against this plasma and field. If the field is as large as required, then the push will be large. This resulting push will significantly alter the system and the spacecraft trajectory. So, in addition to radiation protection, the M2P2 system can potentially provide propulsive thrust for an exploration vehicle.

One side effect is the generation of radiation belts in this field.

This is minimized by running the M2P2 system in a pulsed mode rather than in a continuous fashion. The pulsed mode also allows for the generated field to deflect particles even more efficiently since it inhibits particles from diffusing inward. In addition, this mode seems to require less power to operate than the continuous mode.

B-field simulations have demonstrated the two critical characteristics needed to achieve the required 50% reduction in Galactic Cosmic Ray flux:

1) Simulated field strength scales linearly with number of units, and
2) Field strength behaves with radial distance R as $1/R^2$.

Single unit, 4-unit, and 8-unit configurations have been simulated and their shielding effectiveness tested. Rigidity cutoff contours of these test have shown that:

1) For the single-unit configuration, cutoff of Galactic Cosmic Ray protons with 2.25 GV rigidity and Fe ions with 3.39 GV rigidity can be demonstrated
2) For the 4-unit and 8-unit configurations, cutoff contours show gaps. This suggests a significant increase in the number of units is required and/or re-configuration of the B-field, especially in connection with its strength, is necessary.

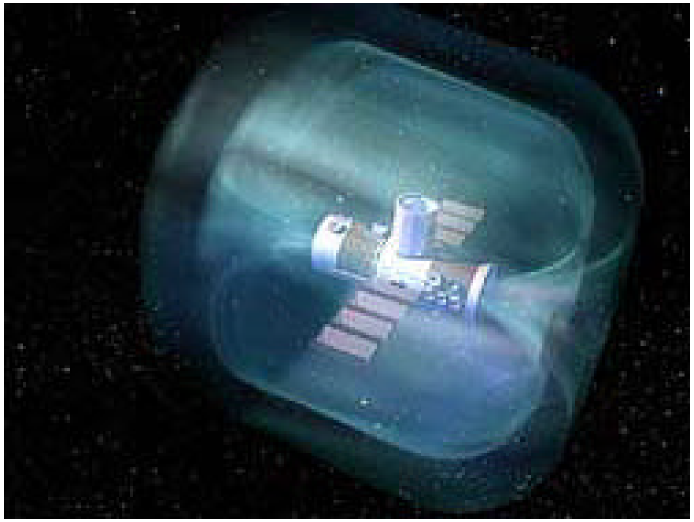
Mini-Magnetospheric Plasma Propulsion (M2P2) for Exploration Missions

Concept:

- A generated magnetic field with the right strength can deflect charged particles; this is the essence of active shielding using a B-field as opposed to passive shielding using materials
- To protect against Galactic Cosmic Rays and Solar Energetic Particles – the two main sources of space radiation hazards – one needs a magnetic field of strength of about 0.1-1 Tesla; power of the order of 100 kW is required to generate this large of a field
- The M2P2 system operates in the solar wind plasma; i.e., solar wind plasma pushes against this plasma and field
- Ion gyro-motion effects are expected to produce directed deflection of the solar wind plasma off the mini-magnetosphere, so the M2P2 system will ***also*** provide radial and azimuthal thrust

FY02 Accomplishments:

- Laboratory testing of the M2P2 prototype has shown that it is an exceptionally efficient plasma source and at electron temperatures several times higher than any laboratory equivalent helicon plasma sources
- Single unit, 4-unit, and 8-unit configurations have been simulated and their shielding effectiveness tested
- B-field simulations demonstrated the two critical characteristics needed to achieve the required 50% reduction in Galactic Cosmic Ray flux



M2P2 Concept in Operation

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